Claims:

1. A method of measuring a DUT comprising the steps of:

providing a vector network analyzer having at least two measurement ports,

measuring a reflection characteristic of a high reflect calibration standard at each measurement port,

measuring forward and reverse reflection and transmission characteristics of a line calibration standard,

measuring forward and reverse reflection and transmission characteristics of a source terminated through calibration standard,

measuring forward and reverse reflection and transmission characteristics of a locally terminated through calibration standard,

calculating error coefficients for said at least two measurement ports based upon results in said steps of measuring,

calculating a shifted electrical length attributable to said calibration standards based upon results in said steps of measuring,

measuring a DUT,

correcting for systematic errors in said step of measuring said DUT based upon said error coefficients to yield a corrected S-parameter

matrix, and

shifting a reference plane for each element of said corrected S-parameter matrix to coincide with a DUT measurement plane.

2. A method of measuring as recited in claim 1 wherein said vector network analyzer comprises more than two measurement ports and wherein said steps of measuring are repeated for all direct pairs of said measurement ports and further comprising the step of measuring a locally terminated through calibration standard for all indirect pairs of measurement ports.

3. A method of measuring as recited in claim 2 wherein a shifted electrical length between said indirect pairs is calculated using load match and source match error coefficient terms.

4. A method of measuring as recited in claim 3 wherein

$$\frac{\Gamma_{SA\_portn}}{\Gamma_{LA\_portm}} = S_{21\_thru\_nm} S_{12\_thru\_nm}$$

wherein $S_{21\_thru\_nm}$ is equal to $S_{12\_thru\_mn}$ and an argument of both solutions for $S_{21\_thru\_nm}$ is fit to a straight line, the solution having a y-intercept closest to zero being the correct solution and the resulting argument of the correct solution being the electrical delay.

5. A method of measuring as recited in claim 2 and further comprising the step of measuring forward and reverse reflection and transmission characteristics of a source terminated through calibration standard for indirect pairs of said measurement ports.

6. A method of measuring as recited in claim 2 wherein transmission tracking error coefficients are calculated using an averaging process for all proximal pairs.

7. A method of measuring as recited in claim 5 wherein said step of calculating further comprises calculating a different respective shifted electrical length for each said direct and indirect pair.

8. A method of measuring as recited in claim 7 wherein said shifted electrical length between proximal pairs is determined by averaging a shifted electrical length between said direct pair and said indirect pair having respective proximal pair measurement ports in common.

9. A method of measuring as recited in claim 5 and further comprising the step of measuring forward and reverse reflection and transmission characteristics

of a locally terminated through calibration standard for proximal pairs of said measurement ports.

10. A method of measuring as recited in claim 9 wherein transmission tracking error coefficients are calculated using said locally terminated through calibration standard for said proximal pairs.

11. A method of measuring as recited in claim 2 wherein said vector network analyzer comprises a multiport test set and switch matrix having said more than two measurement ports.

12. A method of measuring as recited in claim 1 and further comprising the step of determining a type of high reflect calibration standard.

13. A method of measuring as recited in claim 12 wherein said step of determining further comprises calculating a characteristic of said high reflect calibration standard, fitting arguments of two possible solutions for said characteristics to a straight line, identifying which solution is closest to zero phase at DC.

14. A method of measuring as recited in claim 1 wherein said ten error coefficients comprise forward

and reverse reflection tracking error coefficients, wherein said forward and reverse reflection tracking error coefficients are determined using a boundary condition wherein an argument of reflection tracking is zero at DC.

15. A method of measuring as recited in claim 7 and wherein said step of shifting comprises modifying an argument of respective S-parameters of said measured DUT according to respective ones of said shifted electrical lengths.

16. A method of measuring as recited in claim 15 wherein said step of shifting a reference plane comprises adjusting each said element of said corrected S-parameter matrix according to:

$$S_{dut} = |\rho| e^{-j(\theta_0 + \delta\theta(f))}$$

wherein δθ is calculated from said electrical length as a function of frequency.

17. A method of measuring as recited in claim 1 wherein said step of calculating a shifted electrical length comprises calculating a characteristic of said high reflect calibration standard, fitting an argument of said characteristic to a straight line, and using a slope of said straight line to calculate a shifted electrical length.

18. A method of measuring comprising the steps of:

providing a vector network analyzer having at least two measurement ports,

measuring a reflection characteristic of a high reflect calibration standard for each said measurement port,

measuring forward and reverse reflection and transmission characteristics of a line calibration standard between said at least two measurement ports,

measuring forward and reverse reflection and transmission characteristics of a source terminated through between said at least two measurement ports,

measuring forward and reverse reflection and transmission characteristics of a locally terminated through calibration standard between said at least two measurement ports,

calculating forward and reverse reflection tracking error coefficients based upon results from said steps of measuring using a boundary condition wherein an argument of said reflection tracking coefficients are zero at DC,

calculating all remaining forward and reverse error coefficients,

measuring a DUT,

correcting for systematic errors in said step of measuring said DUT based upon said error coefficients.

19. A method of measuring as recited in claim 18 wherein said vector network analyzer comprises more than two measurement ports and wherein said steps of measuring are repeated for direct pairs of said measurement ports and further comprising the step of measuring a locally terminated through calibration standard between indirect pairs of said measurement ports.

20. A method of measuring as recited in claim 18 and further comprising the steps of calculating an electrical length of a shifted reference plane for each said at least two measurement ports based upon results in said steps of measuring and correcting said shifted reference plane to coincide with a DUT measurement plane.

21. A method of measuring as recited in claim 20 wherein said step of calculating a shifted electrical length comprises calculating a characteristic of a high reflect calibration standard, fitting an argument of said characteristic to a straight line and using a slope of said straight line to calculate a shifted electrical length.

22. A method of measuring as recited in claim 19 wherein said steps of measuring a DUT and correcting for systematic errors yields a corrected S-parameter matrix and further comprising the steps of calculating a respective electrical length of a shifted reference plane for each direct pair of measurement ports based upon results in said steps of measuring and shifting respective elements of said corrected S-parameter matrix by respective electrical lengths to coincide with a DUT measurement plane.

23. A method of measuring as recited in claim 20 wherein said step of shifting said shifted reference plane comprises adjusting each said element of said corrected S-parameter matrix according to:

$$S_{dut} = |\rho| e^{-j(\theta_0 + \delta\theta(f))}$$

wherein $\delta(\theta)$ is calculated from said electrical length as a function of frequency.

24. A method of measuring as recited in claim 18 and further comprising the step of determining whether said high reflect calibration standard is an open circuit or a short circuit.

25. A method of measuring as recited in claim 24 wherein said step of determining further comprises fitting arguments of two possible solutions for a reflection tracking error coefficient to a straight line and identifying which solution is closest to zero phase at DC.

26. A method of measuring as recited in claim 19 wherein a shifted electrical length between said indirect pairs is calculated using load match and source match error coefficient terms.

27. A method of measuring as recited in claim 26 wherein

$$\frac{\Gamma_{SA\_portn}}{\Gamma_{LA\_portm}} = S_{21\_thru\_nm} S_{12\_thru\_nm}$$

and $S_{21\_thru\_nm}$ is equal to $S_{12\_thru\_mn}$ and an argument of both solutions for $S_{21\_thru\_nm}$ is fit to a straight line, the solution having a y-intercept closest to zero being the correct solution and the resulting argument of the correct solution being used to determine said shifted electrical length.

28. A method of measuring as recited in claim 19 and further comprising the step of measuring forward and reverse reflection and transmission characteristics of a source terminated through calibration standard for indirect pairs of said

measurement ports.

29. A method of measuring as recited in claim 28 and further comprising calculating a shifted electrical length for each direct and indirect pair of measurement ports.

30. A method of measuring as recited in claim 29 wherein transmission tracking error coefficients are calculated using an averaging process for all proximal pairs of measurement ports.

31. A method of measuring as recited in claim 28 wherein said shifted electrical length between proximal pairs is determined by averaging a shifted electrical length between said direct pair and said indirect pair having respective proximal pair measurement ports in common.

32. A method of measuring as recited in claim 28 and further comprising the step of measuring forward and reverse reflection and transmission characteristics of a locally terminated through calibration standard for proximal pairs of said measurement ports.

33. A method of measuring as recited in claim 32

wherein transmission tracking error coefficients are calculated using results of measurement taken of said locally terminated through calibration standard for said proximal pairs.

34. An apparatus for measuring a DUT comprising:

a vector network analyzer comprising a signal generator and at least two receivers capable of connection to at least two measurement ports,

means for measuring a reflection characteristic of a high reflect calibration standard at each measurement port, measuring forward and reverse reflection and transmission characteristics of a line calibration standard, measuring forward and reverse reflection and transmission characteristics of a source terminated through calibration standard, measuring forward and reverse reflection and transmission characteristics of a locally terminated through calibration standard,

means for calculating ten error coefficients for said at least two measurement ports based upon results of said means for measuring,

means for measuring the DUT,

a processor for calculating a shifted electrical length attributable to said calibration standards, for correcting systematic errors in results from said means for measuring said DUT

based upon said error coefficients to yield a corrected S-parameter matrix, and for shifting a reference plane for each element of said corrected S-parameter matrix to coincide with a DUT measurement plane.

35. An apparatus as recited in claim 34 wherein said vector network analyzer comprises more than two measurement ports and wherein said means for measuring further comprises means for measuring a locally terminated through calibration standard for indirect pairs of measurement ports.

36. An apparatus as recited in claim 35 wherein said processor calculates a respective shifted electrical length between said indirect pairs using load match and source match error coefficient terms.

37. An apparatus as recited in claim 36 wherein

$$\frac{\Gamma_{SA\_portn}}{\Gamma_{LA\_portm}} = S_{21\_thru\_nm} S_{12\_thru\_nm}$$

and $S_{21\_thru\_nm}$ is equal to $S_{12\_thru\_mn}$ and an argument of both solutions for $S_{21\_thru\_nm}$ is fit to a straight line, the solution having a y-intercept closest to zero being a correct solution and a resulting argument of said correct solution being used to determine said shifted electrical delay.

38. An apparatus as recited in claim 35 wherein said processor calculates transmission tracking error coefficients for said proximal pairs using an averaging process.

39. An apparatus as recited in claim 35 and further comprising means for measuring forward and reverse reflection and transmission characteristics of a source terminated through calibration standard between indirect pairs of measurement ports.

40. An apparatus as recited in claim 39 wherein said processor calculates different respective shifted electrical lengths for said direct and indirect pairs of measurement ports.

41. An apparatus as recited in claim 40 wherein said processor calculates said shifted electrical length between proximal pairs by averaging a shifted electrical length between said direct pair and said indirect pair having respective proximal pair measurement ports in common.

42. An apparatus as recited in claim 39 wherein said means for measuring further comprising means for measuring forward and reverse reflection and transmission characteristics of a locally terminated through calibration standard for proximal pairs of

said measurement ports.

43. An apparatus as recited in claim 42 wherein said processor calculates transmission tracking error coefficients using results from said means for measuring said locally terminated through calibration standard for said proximal pairs.

44. An apparatus as recited in claim 35 and further comprising a multiport test set and switch matrix connected to said vector network analyzer for providing more than two of said measurement ports.

45. An apparatus as recited in claim 34 and further comprising means for determining a type of said high reflect calibration standard.

46. An apparatus as recited in claim 45 wherein said means for determining further comprises means for fitting arguments of two possible solutions for a reflection tracking error coefficient to a straight line and means for identifying which solution is closest to zero phase at DC.

47. An apparatus as recited in claim 34 wherein said ten error coefficients comprise forward and reverse reflection tracking error coefficients and

said means for calculating determines said forward and reverse reflection tracking error coefficients using a boundary condition wherein an argument of reflection tracking is zero at DC.

48. An apparatus as recited in claim 34 wherein said measurement ports comprise direct pairs of measurement ports and indirect pairs of measurement ports and wherein said means for calculating said shifted electrical length comprises means for calculating respective ones of said shifted electrical lengths for each direct and indirect pair of measurement ports.

49. An apparatus as recited in claim 48 and wherein said processor for shifting modifies an argument of respective S-parameters of said measured DUT according to respective ones of said shifted electrical lengths.

50. An apparatus as recited in claim 49 wherein said processor for shifting modifies respective elements of said corrected S-parameter matrix according to:

$$S_{dut} = |\rho| e^{-j(\theta_0 + \delta\theta(f))}$$

wherein $\delta\theta$ is calculated from said electrical length as a function of frequency.

51. An apparatus as recited in claim 48 wherein said processor calculates said shifted electrical length by fitting an argument of a characteristic of a high reflect calibration standard to a straight line and using a slope of said straight line to calculate a shifted electrical length.

52. An apparatus for measuring comprises:

a vector network analyzer having at least two measurement ports,

means for measuring a reflection characteristic for each said measurement port, measuring forward and reverse reflection and transmission characteristics for a line calibration standard between said at least two measurement ports and, measuring forward and reverse reflection and transmission characteristics of a source terminated through calibration standard between said at least two measurement ports, and measuring forward and reverse reflection and transmission characteristics of a locally terminated through calibration standard between said at least two measurement ports,

a processor for calculating forward and reverse reflection tracking error coefficients based upon a boundary condition wherein an argument of said reflection tracking error coefficients is zero at DC, and for calculating all remaining forward and reverse error

coefficients,

means for measuring a DUT,

said processor correcting for systematic errors in said means for measuring said DUT based upon said error coefficients.

53. An apparatus as recited in claim 52 wherein said vector network analyzer comprises more than two measurement ports and wherein said means for measuring measures all direct pairs of said measurement ports and further comprising means for measuring forward and reverse reflection and transmission characteristics of a locally terminated through calibration standard between indirect pairs of measurement ports.

54. An apparatus as recited in claim 52 wherein said processor calculates an electrical length of a shifted reference plane for each said at least two measurement ports and corrects said shifted reference plane to coincide with a DUT measurement plane.

55. An apparatus as recited in claim 53 wherein said processor calculates respective electrical lengths of a shifted reference plane for each said direct pair of measurement ports and corrects said shifted reference plane for each said direct pair to

coincide with a DUT measurement plane.

56. An apparatus as recited in claim 55 wherein said processor calculates said shifted electrical lengths by fitting an argument of a characteristic of a high reflect calibration standard to a straight line and using a slope of said straight line to calculate said shifted electrical length.

57. An apparatus as recited in claim 55 wherein said processor shifts said shifted reference plane by adjusting respective elements of a corrected S-parameter matrix according to:

$$S_{dut} = |\rho| e^{-j(\theta_0 + \delta\theta(f))}$$

wherein δθ is calculated from said respective electrical length as a function of frequency.

58. An apparatus as recited in claim 52, said processor also determining a type of said high reflect calibration standard.

59. An apparatus as recited in claim 58 wherein said processor determines said type of high reflect standard by fitting arguments of two possible solutions for a reflection tracking error coefficient to a straight line and identifying which solution is closest to zero phase at DC.

60. An apparatus as recited in claim 53 wherein said processor calculates a shifted electrical length between said indirect pairs using load match and source match error coefficient terms.

61. An apparatus as recited in claim 60 wherein

$$\frac{\Gamma_{SA\_portn}}{\Gamma_{LA\_portm}} = S_{21\_thru\_nm} S_{12\_thru\_nm}$$

and $S_{21\_thru\_nm}$ is equal to $S_{12\_thru\_mn}$ and an argument of both solutions for $S_{21\_thru\_nm}$ is fit to a straight line, the solution having a y-intercept closest to zero being the correct solution and the resulting argument of the correct solution being the electrical delay.

62. An apparatus as recited in claim 54 and further comprising means for measuring forward and reverse reflection and transmission characteristics of a source terminated through calibration standard between indirect pairs of measurement ports.

63. An apparatus as recited in claim 62 wherein said processor calculates a different respective shifted electrical length between each direct and indirect pair of measurement ports.

64. An apparatus as recited in claim 63 and wherein

said processor for shifting modifies an argument of respective S-parameters of said measured DUT according to respective ones of said shifted electrical lengths.

65. An apparatus as recited in claim 64 wherein said processor shifts said shifted reference plane by adjusting respective elements of a corrected S-parameter matrix according to:

$$S_{dutl} = |\rho| e^{-j(\theta_0 + \delta\theta(f))}$$

wherein $\delta\theta$ is calculated from said respective electrical length as a function of frequency.

~~66. An apparatus as recited in claim 63 wherein~~ said processor calculates a shifted electrical length between proximal pairs by averaging a shifted electrical length between said direct pair and said indirect pair having respective proximal pair measurement ports in common.

67. An apparatus as recited in claim 63 wherein said means for measuring further comprises means for measuring forward and reverse reflection and transmission characteristics of a locally terminated through calibration standard for proximal pairs of said measurement ports.

68. An apparatus as recited in claim 67 wherein said processor calculates transmission tracking error coefficients using results of a measurement of said locally terminated through calibration standard for said proximal pairs.

69. An apparatus as recited in claim 63 wherein said processor calculates a shifted electrical length for proximal pairs of measurement ports from an average of shifted electrical lengths for direct and indirect pairs having proximal pair measurement ports in common.

70. An apparatus as recited in claim 69 and wherein said processor for shifting modifies an argument of respective S-parameters of said measured DUT according to respective ones of said shifted electrical lengths.

71. A method of measuring a device under test comprising the steps of:

obtaining measured S-parameter characteristics of a reflect, a line, and a through calibration standard over a range of stimulus frequencies for each port of the device under test,

calculating forward and reverse reflection tracking error coefficients based upon results from said measured characteristics using a boundary

condition wherein an argument of said reflection tracking coefficients are zero at DC,

calculating all remaining forward and reverse error coefficients,

obtaining measured S-parameters characteristics of a DUT over said range of frequencies,

correcting for systematic errors in said measured S-parameter characteristics of said DUT based upon said error coefficients.

72. Computer readable media tangibly embodying a program of instructions executable by a computer to perform a method of determining actual S-parameter ~~characteristics of a device under test based upon~~ measured S-parameter characteristics of said device under test, the method comprising:

obtaining measured S-parameter characteristics of a reflect, line, and through calibration standards over a range of stimulus frequencies for each port of the device under test,

calculating forward and reverse reflection tracking error coefficients based upon results from said measured characteristics using a boundary condition wherein an argument of said reflection tracking coefficients are zero at DC,

calculating all remaining forward and reverse error coefficients,

obtaining measured S-parameters characteristics of said device under test over said range of frequencies,

correcting for systematic errors in said measured S-parameter characteristics of said device under test based upon said error coefficients.